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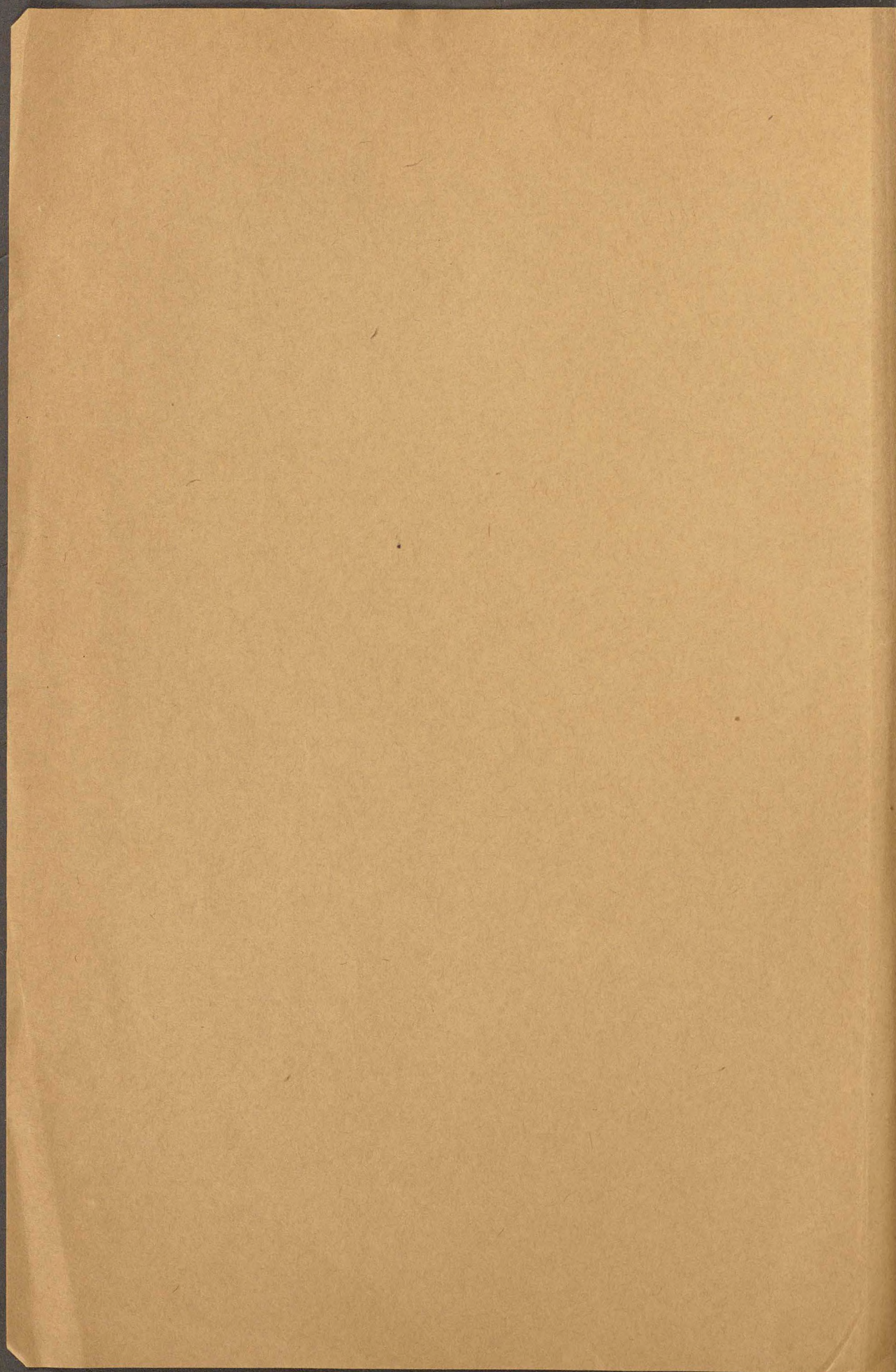
Ferromagnetic Ferric Oxide, Artificial and Natural

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MINERAL CHEMISTRY.—*Ferromagnetic ferric oxide, artificial and natural.*¹ ROBERT B. SOSMAN and E. POSNJAK, Geophysical Laboratory, Carnegie Institution of Washington.

Ferric oxide (Fe_2O_3) can exist at atmospheric temperatures in two different forms. One, the mineral *hematite*, is paramagnetic, like most of the compounds of iron. The other form is ferromagnetic, like magnetite and metallic iron.

Although the existence of a ferromagnetic modification of Fe_2O_3 has been known for over sixty years, comparatively little experimental study has been made of this interesting substance. Furthermore, it has been known heretofore as an artificial product, and only within the past few years has it been observed in nature.

The purpose of this note is to set down some experimental facts obtained by us several years ago concerning this ferromagnetic oxide, particularly the relation of its structure and magnetic properties to those of magnetite, and to describe a natural occurrence of the oxide.

DISTINCTION FROM "MAGNETIC HEMATITE"

It is important at the outset to distinguish clearly between so-called "magnetic hematite" and ferromagnetic ferric oxide.

Natural hematite, particularly in its well-crystallized varieties, is seldom if ever quite free from ferrous iron, held in combination as an oxide of some kind. The ferrous iron may be present as a constituent of intergrown magnetite (Fe_3O_4); or it may be present as a constituent of a solid solution.² In either case, the specific magnetic susceptibility (susceptibility per gram) increases with the percentage of ferrous iron, starting at about 0.000 02 for pure Fe_2O_3 , and culminating at magnetite, whose maximum susceptibility per gram is of the order of 2. The series thus covers a range of 100,000-fold in susceptibility.

Correspondingly, we have found³ that the force exerted by a non-uniform magnetic field upon powdered specimens of the oxides covers a range of about 1 to 5000. A particular specimen of natural oxide of iron may fall anywhere in this series, with a content of FeO anywhere between zero and 31.03 per cent.

¹ Received July 5, 1925.

² SOSMAN AND HOSTETTER, *The oxides of iron. I. Solid solution in the system $\text{Fe}_2\text{O}_3\text{-Fe}_3\text{O}_4$* . Journ. Amer. Chem. Soc. **38**: 807-833. 1916.

³ SOSMAN AND HOSTETTER, *The ferrous iron content and magnetic susceptibility of some artificial and natural oxides of iron*, Trans. Amer. Inst. Mining Eng. **53**: 409-433. 1917. (Also Bulletin, pp. 907-931.)

Since the magnetic susceptibility mounts so rapidly with the ferrous iron content, there is required only a few tenths of a per cent of FeO to cause the powdered specimen to move visibly in a magnetic field. This is particularly the case when tests are made with the ordinary small horseshoe or bar magnet, because the gradient found near the surface of such a magnet may be fairly intense. For this reason, specimens containing relatively little ferrous iron may be classed by the prospector or the mineralogist as "magnetic hematite" or "magnetic iron ore," because they will adhere to a hand magnet.

TRUE MAGNETIC FERRIC OXIDE

Very different is the true ferromagnetic oxide which forms the subject of this paper. It contains no ferrous iron, yet is as magnetic as magnetite itself, at least so far as can be told from the properties of the powdered oxides.

Ferromagnetic ferric oxide has been obtained only in finely divided form. The intensity of magnetization obtainable with any powder is very much less than that obtainable with the same amount of material in the form of a single continuous fragment, especially if in the shape of a bar or rod. The ferromagnetic oxide must therefore be compared with magnetite powdered to a similar degree of fineness.

The intensity of magnetization also varies with the size of the grains, their shape, and their relative orientation. Hence two ferromagnetic substances in powdered form can not be compared with any great exactness. The effects of size and shape of grain, however, may cover a range of twofold or threefold, while ferromagnetic substances differ from paramagnetic by many thousandfold. There need never be any question, therefore, whether or not a given powdered substance is ferromagnetic, nor whether its susceptibility is of the same order of magnitude as that of some other substance taken as a standard for comparison.

HISTORICAL REVIEW

The earliest recorded observation of the properties of ferromagnetic ferric oxide is that of Robbins,⁴ in the "Notes and Queries" of the first volume of *Chemical News*. He prepared it by the oxidation of magnetite, both by heating in air and by fusion with KNO₃. He showed that the product was free from ferrous iron when dissolved.

⁴ ROBBINS, J., *Magnetic peroxide of iron*, Chem. News 1: 11-12. 1859.

The oxide was independently discovered by Malaguti⁵ a few years later; he prepared it by oxidation and ignition of precipitated ferrous hydroxide, and also by ignition of certain hydrated oxides.

Thirty years later Liversidge⁶ observed that various specimens of oxide produced by the rusting of iron in air were ferromagnetic, although most of them contained no ferrous iron. Similar specimens were also made artificially.

The most complete data are by Hilpert,⁷ who made the ferromagnetic oxide by oxidizing either precipitated magnetite or ferrous hydroxide with soluble oxidizing agents.

Within the present year the oxide has again been rediscovered twice; first by Abraham and Planiol,⁸ who have added no new information to the facts already known, and again by Chevallier,⁹ who obtained some new data on its magnetic properties.

Sarzeau¹⁰ and J. Lawrence Smith¹¹ may have been dealing with this same ferromagnetic oxide, but the evidence is not clear, since it is also possible that they had magnetic ferrites or ferric oxide containing magnetite.

PREPARATION OF ARTIFICIAL FERROMAGNETIC FERRIC OXIDE

Our specimens of the oxide were made from precipitated magnetite. To a warm solution containing ferrous and ferric sulfates, in the proportion of one equivalent of ferrous to two of ferric iron, was added a warm solution of sodium hydroxide. The black magnetic precipitate was filtered off and washed. Part of it was shaken up with a warm solution of ammonium persulfate, NH_4SO_4 , until completely oxidized. (No. 2005.) Analysis showed the presence of

⁵ MALAGUTI, F., *Sur le sesquioxyde de fer attirable à l'aimant*, Compt. rend. Acad. Sci. Paris **55**: 350-352. 1862. Ann. Chim. et Phys. (3) **69**: 214-224. 1863.

⁶ LIVERSIDGE, A., *On iron rust possessing magnetic properties*, Rep. Australasian Assoc. Adv. Sci. **1892**: 302-320.

⁷ HILPERT, S., *Ueber Beziehungen zwischen chemischen Konstitution und magnetischen Eigenschaften bei Eisenverbindungen*, Ber. Deutsch. Physik. Ges. **11**: 293-299. 1909. Also Ber. Deutsch. Chem. Ges. **42**: 2248-2261. 1909. Journ. Iron and Steel Inst. **82**: 65-68. 1910.

⁸ ABRAHAM, H., AND PLANIOL, R., *Sur le sesquioxyde de fer magnétique*, Compt. rend. Acad. Sci. Paris **180**: 1328-1329. 1925.

⁹ CHEVALLIER, R., *Sur l'oxyde ferrique ferromagnétique*, Compt. rend. Acad. Paris **180**: 1473-1475. 1925.

¹⁰ SARZEAU, Chem. News **1**: 137. 1860.

¹¹ SMITH, J. LAWRENCE, *Singular anomaly of the sesquioxide of iron as prepared from meteoric iron*, Amer. Chemist **5**: 356-358. 1875. Chem. News **31**: 210-212. 1875. Compt. rend. Acad. Sci. Paris **80**: 301-304. 1875. *Original researches in mineralogy and chemistry* (1884) pp. 480-486.

0.7 per cent FeO. Another part oxidized spontaneously in air when dried at about 105°. (No. 2007.)

A second preparation of precipitated magnetite (No. 2006), made in the same way, was preserved by drying over sulfuric acid and then over phosphorus pentoxide in a vacuum, but even with these precautions was found, after the magnetic tests, to be nearly half oxidized, containing 17.4 per cent FeO, 80.1 per cent Fe₂O₃, and 1.35 per cent H₂O.¹² Several years later, after having stood at room temperature in air, it was found to have changed in color to the brown shade characteristic of ferromagnetic Fe₂O₃ (No. 2006a).

We find also that the dehydration of the mineral lepidocrocite, Fe₂O₃·H₂O, yields a ferromagnetic ferric oxide, while similar dehydration of goethite, the other form of the monohydrate, yields only paramagnetic Fe₂O₃. These two are the only clearly defined crystalline hydrates of ferric oxide.¹³

This interesting reaction, the production of a ferromagnetic from a paramagnetic substance by dissociation, is being further studied. The only specimen available for quantitative examination was made from lepidocrocite from Easton, Pennsylvania, by heating it in a glass dish for 10 days at 320°, and was only about half as magnetic as magnetite; but it was not homogeneous, as it contained portions of much greater and much less susceptibility than the average for the whole. Whether the reaction produced a certain proportion of inert oxide, or whether an original product of high susceptibility has undergone irreversible change during the long heating at 320° (see p. 338) remains to be seen. The product contained no detectable ferrous iron.

NATURAL FERROMAGNETIC FERRIC OXIDE

While these experiments were being conducted (in 1916) we received from Messrs. L. C. Graton and B. S. Butler a specimen of polarized magnetic ferric oxide (No. RC1487). The specimen was in the form of a light chocolate brown powder containing yellowish brown specks, and was collected from a gossan deposit, at Iron Mountain, in the Shasta County copper district, California. A partial analysis by J. C. Hostetter yielded the results shown in Table 1.

The tests described in later paragraphs show that this specimen corresponds in properties to artificial ferromagnetic ferric oxide. Unfortunately it is not very pure. In particular, it contains 2.40

¹² Analysis by J. C. Hostetter of this Laboratory.

¹³ POSNJAK, E., AND MERWIN, H. E., *The hydrated ferric oxides*, Amer. Journ. Sci. 47: 311-348. 1919.

per cent of FeO, which might be suspected of causing a part at least of the high magnetic susceptibility. But the presence of considerable volatile matter in addition to water suggests that this ferrous iron may be present largely as carbonate and sulfide. Even if it were all in solid solution or in the form of magnetite, it could account for only about one-eighteenth of the observed susceptibility.

TABLE 1.—ANALYSIS OF POLARIZED MAGNETIC FERRIC OXIDE

	PER CENT
Ferrous, iron, calculated as FeO.....	2.40
Water, removed at red heat.....	3.1
Other volatile matter, removed at red heat.....	2.5
Insoluble in HCl, mostly quartz, with few large opaque crystals, probably pyrite.....	1.80
Calcium oxide, CaO.....	Present
Ferric oxide, Fe ₂ O ₃ (85.0 and 85.5).....	85.3

A natural ferric oxide differing from hematite in physical properties as much as this one does deserves a separate mineral name. It would be desirable, however, before assigning such a name, to have a type specimen which was more nearly pure Fe₂O₃ than the one in hand.

MAGNETIC APPARATUS

The apparatus used for magnetic tests will be more fully described in another publication. It consists of two concentric solenoids, of which the inner furnishes a uniform magnetic field while the outer furnishes a field having a gradient. The two can be independently varied. The force acting on a specimen suspended in the axis of the solenoids is weighed directly on an analytical balance sensitive to 0.01 mg.

With a paramagnetic substance such as ferrous sulfate the force is proportional to the magnetic susceptibility, the field strength, and the field gradient, and absolute measurements of the susceptibility of the compounds of iron can be made with an accuracy of two per cent or better. But with a ferromagnetic substance, as already noted, the force depends not only on the factors mentioned but also on fineness of grain, shape of grains, shape of the charge as a whole, and previous magnetic history. Therefore only somewhat crude comparative results are obtainable with a ferromagnetic powder, but the method has the advantage of being adaptable, without change in the apparatus, to a wide range of susceptibilities.

MAGNETIC RESULTS

Reproducibility. A set of 5 measurements on Mineville magnetite No. 3b, 170 to 200 mesh, confirmed the conclusion reached in our earlier measurements with a cored electromagnet,¹⁴ that the attraction per gram on a ferromagnetic powder of given size of grain and shape of charge is reproducible within one per cent. The charge was taken out and mixed between measurements, and the effect of depolarizing it by gradual withdrawal from an alternating field was also tried.

Effect of position. The field and gradient, and hence the force, vary with the position of the charge with reference to the solenoids. The charge was always suspended so as to be coaxial with the solenoids, and the position of its center, with reference to the top of the outer solenoid as zero, was measured to 0.2 mm. The variation as actually measured agreed with that calculated from the dimensions of the solenoids.

Shape of charge. The shape of the sample is without effect on the force exerted upon a paramagnetic substance. With a ferromagnetic substance, on the contrary, it is one of the most important variables. Measurements were therefore made with varying amounts of the ferromagnetic powders contained in cylindrical brass containers of 6 and 10 mm. diameter. The results are incorporated in figures 1 and 2. All of these measurements were made in a field whose intensity on the axis was about 700 gilbert-per-cm., with a gradient of 14.5.

The shape of the curves depends upon the complex relation existing between the demagnetizing factor of the individual grain, due to its individual shape and size; the mutual inductive effect of the grains, depending on their relative position and distance apart; and the demagnetizing factor of the charge as a whole, depending upon its over-all shape and size.

The important fact brought out by the curves for magnetite in figure 1, and for artificial ferromagnetic Fe_2O_3 and the corresponding natural oxide in figure 2, is the agreement in order of magnitude of the magnetization, as indicated by the force. All are seen to be ferromagnetic, and to have similar values of susceptibility, although the absolute values can not be deduced from these data. Also, the curves for the three are similar in form.

Effect of grain size. Three sizes of grain of natural magnetite are

¹⁴ SOSMAN AND HOSTETTER, Op. cit. (Trans. Amer. Inst. Mining Eng. 53) p. 414.



Fig. 1



Fig. 2

Figs. 1 and 2.—Comparative magnetic susceptibilities of magnetite and artificial and natural ferromagnetic oxide.

compared in figure 1: one collected between sieves having 170 and 200 meshes per inch, average grain size 0.12 mm.; another between 300 and 325 meshes, 0.07 mm.; and a third size separated by means of the 1-mm. jet in an air elutriator,¹⁵ grains about 0.01 mm. The results confirm the general statement made in the earlier paper,¹⁶ that diminution in grain size diminishes the magnetization. In both cases the change from 0.12 to 0.07 mm. average diameter corresponds to a decrease of about 3 per cent.

TABLE 2.—COMPARATIVE DATA ON SUSCEPTIBILITY AND REMANENCE OF OXIDES OF IRON

SUBSTANCE	FORM	DIAMETER OF CONTAINER	SPECIMEN NUMBER	MAXIMUM ATTRACTION PER GRAM	SUSCEPTIBILITY $10^6/m$	REMANENCE IN PER CENT OF MAXIMUM
		mm.		mg.		
Magnetite, Mineville, N. Y.....	170-200 mesh	10	3b	598		
Magnetite, Mineville, N. Y.....	300-325 mesh	10	3b	580		5*
Magnetite, Mineville, N. Y.....	300-325 mesh	6	3b	652		
Magnetite, Mineville, N. Y.....	Elutriated powder	6	3b	595		11
Precipitated Fe_3O_4 , partly oxidized.	Very fine powder	6	2006	670		4
Artificial ferromagnetic Fe_2O_3	Very fine powder	6	2005	597		3
Artificial ferromagnetic Fe_2O_3	Very fine powder	6	2007	576		4*
Natural ferromagnetic Fe_2O_3	Coarse powder	10	RC1487	568		15*
Natural ferromagnetic Fe_2O_3	Fine powder	10	RC1487	560		15
Natural ferromagnetic Fe_2O_3	Fine powder	6	RC1487	606		14
Natural ferromagnetic Fe_2O_3 (heated to about 600°).....	Fine powder	6	RC1487	558		
Same, heated to 750°	Fine powder		RC1487	4.20	400	19
Ferrous ammonium sulfate, $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$	Powder		6211	0.33	31	
Purest ferric oxide.....	Powder		1041	0.21	20	

* See curve in figure 3.

The artificial (precipitated) and partly oxidized magnetite (No. 2006) is much finer than the natural fractions, but is nevertheless of somewhat higher susceptibility.

The maximum values are compared in Table 2.

¹⁵ SOSMAN AND HOSTETTER, Op. cit. (Trans. Amer. Inst. Mining Eng. 58) p. 414.

¹⁶ Ibid., p. 415.

Remanence. The remanence (also called "residual magnetization," "permanent magnetization," or "magnetic polarization") of magnetite and ferromagnetic oxide could also be compared in the apparatus described. For the measurement, the current of the outer solenoid was kept constant, maintaining a constant gradient, after the current in both solenoids had been carried through a cycle from maximum positive to maximum negative and part of the way back. By continuing the cycle with the current of the inner solenoid, the field intensity

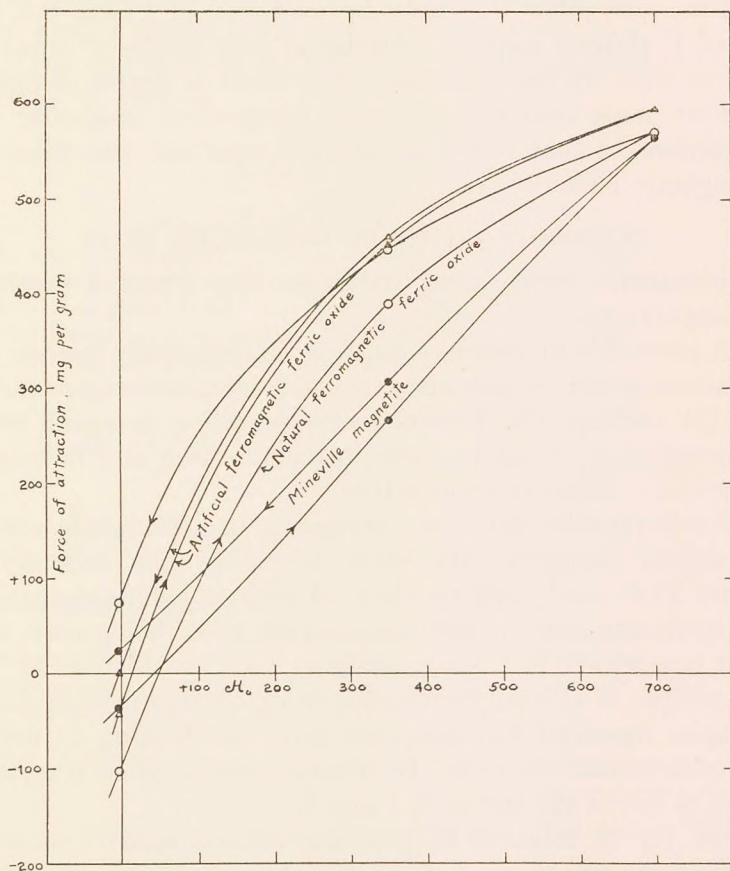


FIG. 3.—Relative forms of hysteresis loops of magnetite and ferromagnetic ferric oxides.

at a given point on the axis was thus brought twice to the value zero. The mean value of the force of attraction at these two points gives some idea of the remanence. As before, we get only a rather crude relative value, since the demagnetizing factors of grains and of charge enter into the effect, in addition to the fundamental fact that only an apparent remanence, dependent on the coercive force of the material, can be measured on a specimen in other than ring form.

The results, expressed in percentages of the maximum attraction, are included in Table 2.

Hysteresis loop. The remanence is only one of the characteristics of the hysteresis loop, whose relative form can also be compared by means of the apparatus described. Typical curves are shown in figure 3. The form of curve is found to be distinctly different for natural magnetite, artificial ferromagnetic oxide, and natural ferromagnetic oxide. This may indicate that the natural specimen was formed in some other way than by oxidation of Fe_3O_4 , but further study of hysteresis loops as correlated with mode of formation is needed to clear up this question. The effect of degree of fineness is not known with certainty, although fine-grained magnetite gave a curve similar to that shown in figure 3, and not like those of the ferromagnetic ferric oxides.

INVERSIONS IN THE FERROMAGNETIC OXIDE

Ferromagnetic ferric oxide undergoes two types of inversion at high temperatures:

(1) A reversible inversion, consisting in a relatively sudden change from ferromagnetic to paramagnetic at a temperature not far above 500° . On cooling, the ferromagnetic condition is again assumed. This inversion is similar to those in metallic iron and in magnetite, although at a different temperature.

(2) An irreversible inversion, consisting in a complete loss of the ferromagnetic property, the oxide becoming like ordinary paramagnetic Fe_2O_3 and perhaps identical with it. This change occurs at an increasing rate as the temperature rises, being slow at 500° while it is complete in a few minutes at 650° and higher.

The sample of natural ferromagnetic oxide described in preceding paragraphs remained ferromagnetic after the heating to determine water and volatile matter. Its characteristics after being heated are seen in one of the curves of figure 2.

Heated for 15 minutes at 750° the natural oxide became paramagnetic, lowering the force of attraction per gram to the value shown near the bottom of figure 2.

Some natural magnetite which had been partially oxidized by heating in moist oxygen at 400 to 470° for 20 to 45 hours yielded only a paramagnetic oxide, as shown by the fact that the susceptibility was about that corresponding to the ferrous iron content.¹⁷

¹⁷ SOSMAN AND HOSTETTER, Op. cit. (Trans. Amer. Inst. Mining Eng. 58) p. 423.

COLOR OF THE FERROMAGNETIC OXIDE

Some data on the colors of the powders of the natural and artificial ferromagnetic oxides are assembled in Table 3, with similar data on specimens of ordinary ferric oxide for comparison. The numbers and names are those used by Ridgway.¹⁸

Those familiar with Ridgway's system of numbering colors will see at once that the color of the ferromagnetic oxide is distinctive. It is further toward the yellow than the paramagnetic, and of a slightly deeper shade, and so tends toward a "chocolate brown" color. The difference is not one that could be produced by a different degree of fineness.

TABLE 3.—COLORS OF OXIDES OF IRON IN POWDER FORM

	SPECIMEN NUMBER	COLOR NUMBER	COLOR NAME
Natural magnetite, Mineville.....	3b		Black, lustrous
Artificial ferromagnetic Fe ₂ O ₃	2005	6'm	Hessian brown to liver brown
Artificial ferromagnetic Fe ₂ O ₃	2007	7m	Bay
Natural ferromagnetic Fe ₂ O ₃ coarse..	RC1487	9''m	Burnt umber
Natural ferromagnetic Fe ₂ O ₃ fine ...	RC1487	11'k	Hazel
Natural ferromagnetic Fe ₂ O ₃ heated to about 600°.....	RC1487	69'''m	Aniline black
Natural ferromagnetic Fe ₂ O ₃ heated to 750°.....	RC1487	7'j	Vinaceous-rufous to Hay's russet
"Reagent" Fe ₂ O ₃ , Merck.....	1041	5''j	Ocher red to Prussian red
Fe ₂ O ₃ from hydrolysis of nitrate....	231	5'j	Dragons-blood red to brick red
Oxidized magnetite, not ferromag- netic.....	242	1''k	Mineral red
Specular hematite, L. Superior.....	1058	5k	Morocco red
"Magnetic hematite," Juragua, Cuba.	1092	69'''k	Anthracene purple
Natural goethite, Diamond Hill, R. I.....	17879	13'm	Mars brown
Natural limonite, Urals, Russia.....	40352	17'k	Dresden brown

Other investigators have also observed this color difference. Abraham and Planiol call the ferromagnetic oxide "a slightly yellowish brown," and Chevallier, "more yellowish than ordinary ferric oxide."

REFRACTIVE INDEX OF FERROMAGNETIC OXIDE¹⁹

The refractive index is difficult to measure because of the fineness of grain. The natural oxide (RC1487) is mostly either isotropic or

¹⁸ RIDGWAY, R., *Color standards and color nomenclature*, Washington, 1912.

¹⁹ We are indebted to Dr. H. E. Merwin of this Laboratory for this examination.

in such fine-grained aggregates that no birefringence is evident, but a few distinctly birefringent fibrous aggregates are present. The grains are porous, as is evident from the penetration of liquids used for mounting. The refractive index of grains which the liquid has penetrated is about 2.52 for red light. This is somewhat nearer to the average index of goethite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$) than to that of hematite (Fe_2O_3). As the specimen contains 3.1 per cent of water, this measurement is not decisive as to the index of the ferromagnetic oxide. The maximum index obtained with the oxide derived from lepidocrocite is equal to the minimum index of hematite (2.74).

It is evident, then, that the indices of the ferromagnetic oxide are not radically different from those of hematite, but no more exact quantitative statement can be made until visible crystals are available.

STRUCTURE OF FERROMAGNETIC OXIDE

One of the most interesting facts about the ferromagnetic oxide is the close relation of its structure to that of magnetite.

TABLE 4.—DATA SHOWING APPARENT IDENTITY OF STRUCTURE BETWEEN MAGNETITE (Fe_3O_4) AND FERROMAGNETIC FERRIC OXIDE (Fe_2O_3)

MAGNETITE. MINEVILLE, 3b			OXIDIZED PRECIPITATED MAGNETITE NO. 2005			OXIDIZED PRECIPITATED MAGNETITE NO. 2006		
x cm	I	d/n $m\mu$	x cm	I	d/n $m\mu$	x cm	I	d/n $m\mu$
2.51	9—	0.300	2.62	5	0.292	2.61	5—	0.293
2.97	10	0.2535	3.055	10	0.252	3.06	10	0.251
3.59	4	0.210	3.66	3	0.210	3.65	4	0.2105
						4.10 (?)	1/2	0.187
						4.50 (?)	1/2	0.171
4.685	6—	0.161	4.84	6	0.159	4.81	7	0.160
5.12	8	0.1475	5.245	9	0.147	5.26	9	0.147
5.94	2	0.128	6.15 (?)	1/2	0.126			
6.28 (?)	1/2	0.121						
6.58 (?)	1/2	0.116						
7.02	1—	0.109	7.11 (?)	1/2	0.1095			
7.92	1—							

Following up a suggestion made in 1917,²⁰ one of the authors (E. P.) made some X-ray diffraction measurements on natural magnetite and ferromagnetic ferric oxide, by the so-called powder method. The films were made in 1922 but the results have not heretofore been published.

²⁰ SOSMAN, R. B., p. 67 of *Some problems of the oxides of iron*, This JOURNAL 7: 55-72. 1917.

Table 4 shows the comparison. Under each substance is given: first, the distance (x) of each spectrum line from the central undeviated image, obtained by measuring the distance between corresponding lines on opposite sides of the center of the film and dividing by 2; second, the relative intensity (I) of the line, judged visually; third, the fractional spacing of atomic planes (d/n) corresponding to the line, in $m\mu$ (10^{-6} mm.). This third quantity is based upon the equation $n\lambda = 2d \sin \theta$, in which n is the order of reflection, λ is the wave-length of X-rays used ($K\alpha$ line of molybdenum, 0.712 Å.), d is the distance between like planes of atoms, and θ is the angle of reflection, determined from x with the aid of a calibration of the X-ray camera with sodium chloride.

The table shows practically complete identity between the three patterns. The only discrepancy which seems in excess of the normal error is in the line closest to the center; at this line, agreement is complete between the two ferric oxides but the magnetite shows a greater intensity and slightly larger spacing. But it should be remarked that the films are rather weak, with much scattering (the technique has since been improved) and it cannot be asserted that this one difference is real.

Welo and Baudisch²¹ have recently reported confirmation of this identity of pattern, with the aid of X-ray photographs by W. P. Davey, but their results have not yet been published in full.

The theoretical importance of this transformation has already been commented upon,²² but the explanation for the persistence of magnetic properties and of structure is not yet clear.

If the identity of X-ray pattern shall be found to be complete, it will furnish a second instance of two compounds which differ in composition and physical properties but give the same X-ray pattern.²³

SUMMARY

The ferromagnetic modification of ferric oxide, long known only as an artificial product, has now been found in nature. The properties of this specimen are compared with the properties of Mineville magnetite and of artificial ferromagnetic Fe_2O_3 made by oxidizing precipitated Fe_3O_4 . The three are similar in magnetic susceptibility,

²¹ WELO, L. A., AND BAUDISCH, O., *The two-stage transformation of magnetite into hematite*, Abstract of paper before American Physical Society. *Physical Rev.* **25**: 587. April, 1925.

²² SOSMAN, Op. cit. (This JOURNAL **7**: 66).

²³ The other case is that of sillimanite ($Al_2O_3 \cdot SiO_2$) and mullite ($3Al_2O_3 \cdot 2SiO_2$). See BOWEN AND GREIG, *Journ. Amer. Ceramic Soc.* **7**: 253. 1924.

and give the same X-ray pattern, in spite of the radical difference in composition between Fe_3O_4 and Fe_2O_3 . The ferromagnetic oxides are similar in color and differ in color from ordinary Fe_2O_3 . The natural specimen gives a different hysteresis curve from the artificial oxide and from magnetite. The ferromagnetic property of Fe_2O_3 is lost reversibly at a definite temperature a little above 500° , and irreversibly at 650° and possibly lower, depending upon the time of heating. A ferromagnetic oxide has also been obtained by the dehydration of lepidocrocite, one of the two crystalline forms of the monohydrate $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, while the other form, goethite, yields only paramagnetic Fe_2O_3 .

4. Rost. —
(see Lepidocrocite)

